APPENDIX S. PIÑON-JUNIPER FOREST ECOSYSTEMS IN THE SOUTHERN PLAINS NETWORK: A DESCRIPTION AND CONCEPTUAL MODEL

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INTRODUCTION TO PIÑON-JUNIPER FORESTS

Piñon-juniper forests cover a significant portion of Western and Southwestern United States (Davenport, et al. 1998). Stands of piñon-juniper forests are most often found in arid to semi-arid watersheds. Piñon-juniper forests are characteristically comprised of relatively small, xeric coniferous trees, which tend to be drought-resistant and cold-tolerant, and that form an open canopy. The understory will likely consist of mixed-grasses and shrubs. The composition and relative dominance of the contrasting functional groups that form the canopy and the ground cover will highly influence piñon-juniper ecosystems (Breshears and Barnes 1999, Whitford 2002;). This influence can be demonstrated through rates of transpiration (Kerkhoff et al. 2004), soil infiltration and erosion, and nutrient cycling (Schlesinger et al. 1996). The positive feedback loop between soil, vegetation, and climate in Piñon-Juniper forests ten to make them especially sensitive to anthropogenic changes in land use and global climatic changes.

Major droughts can strongly affect the distribution and community structure of Piñon-Juniper forests Although they are capable of surviving on a variety of soil types (Wilcox and Davenport 1995) their soils will typically be aridsols, mollisols, or entisols and will commonly be derived from basalt, limestone, and sandstone parent materials.

Piñon-juniper forests can provide unique and often irreplaceable ecological services, including plant and animal habitats, food for herbivores, nutrient cycling, and water capture and retention (Whitford 2002). However, piñon-juniper forest ecosystems have exhibited widespread and rapid changes over the past century, which has often produced adverse ecological effects and caused interruptions to their ecological services. In particular, increased woody-plant density and range expansion have facilitated erosion, debilitated soil processes, eliminated habitat, and diminished forage productivity (Peiper 1990; Kerkhoff 2004). An additional concern of increasing woody-plant density that Southern Plains Network (SOPN) Park managers are currently facing is the recent infestation of the Ips beetle (*Ips confuses*), which is taking advantage of the changes in piñon-juniper forests

CONCEPTUAL MODEL FOR PIÑON-JUNIPER ECOSYSTEM

Quantitative and qualitative analyses suggest that woody-plant abundance has substantially increased in grasslands in the Southwest region of North America over the last two centuries and replaced grasslands in the process (Hobbs and Mooney 1986; Archer 1989). While a growing number of studies have focused on the mechanisms controlling this trend, factors that make an ecosystem more or less susceptible to woody-plant encroachment are not entirely clear. Figure 1 explains the general ecosystem dynamics controlling a piñon-juniper forest; Figure 2 is a conceptual model adapted from Archer (1989) that depicts the transition in community structure between woody-plant and grassland ecosystems; Figure 3 illustrates the ball-and-cup theory of a ecosystem stability and the energy needed to an ecosystem past a threshold by which it will become an altered state. The narrative that follows will describe this model in the context of piñon-juniper forest ecosystems at Pecos National Historical Park (PECO) and Capulin Volcano National Monument (CAVO).

Within grassland communities, grazing pressure will change the composition and productivity of herbaceous species while decreasing fire fuel load. Therefore, the probability of piñon-juniper encroachment increases (shrub-driven succession). Alternatively, if grazing pressure is reduced in a grassland that borders a piñon-juniper forest, succession toward a stronger grass-dominated community may arise (Graminoid-driven succession). However, if an adequate number of piñon-juniper trees become established in a grass-dominated community, successional processes will shift the community towards a “steady-state”, or alternative-state (Chapin et al. 1996), condition. Once a community has become dominated by piñon-juniper trees, the area will not revert to a grassland without a considerable amount of energy input, especially if the displaced grassland plants were established under different climatic conditions. Returning a community to a less piñon-juniper-dominated and a more grass-

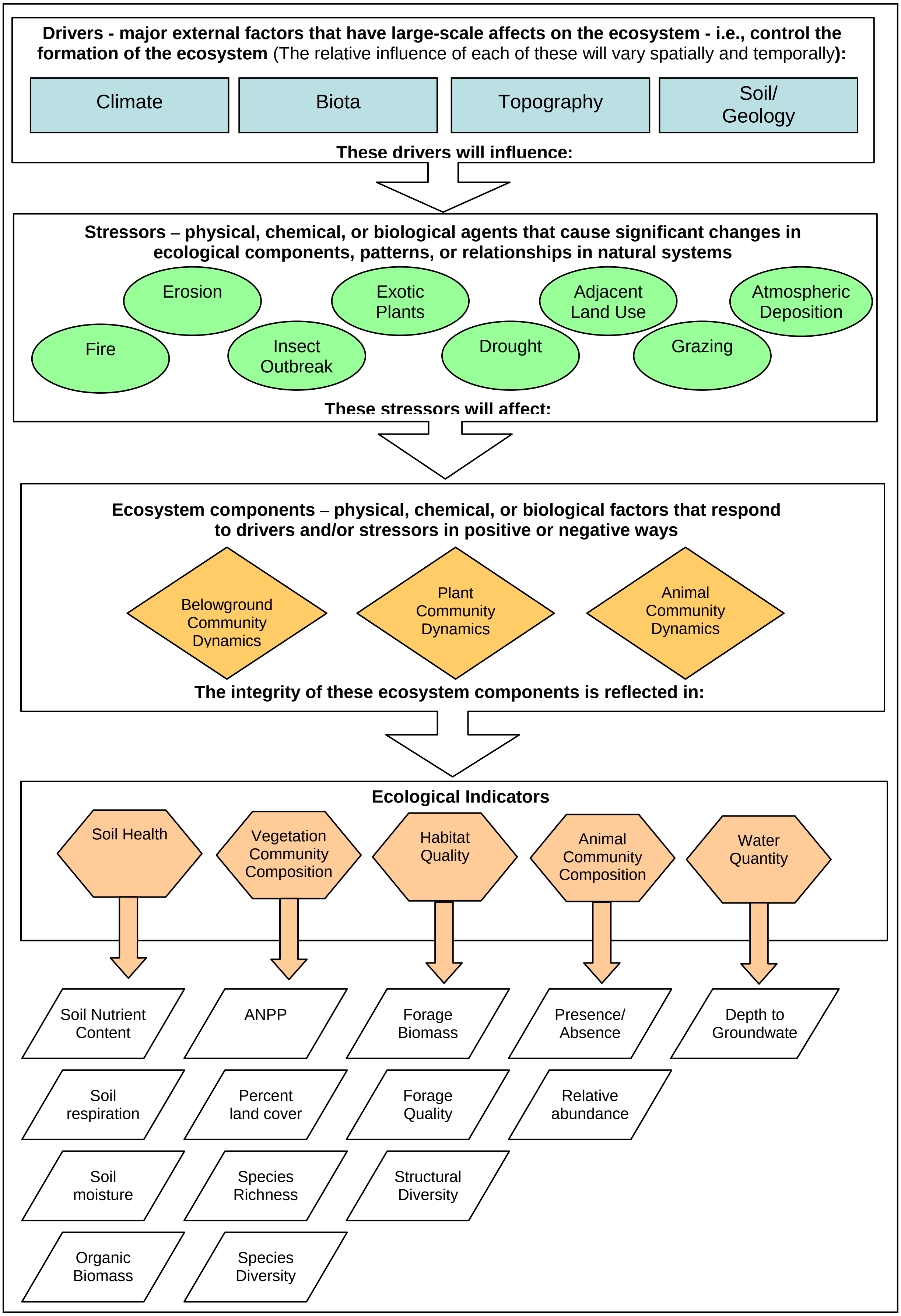

Figure 1. Piñon-Juniper Forest Ecosystem Conceptual Model

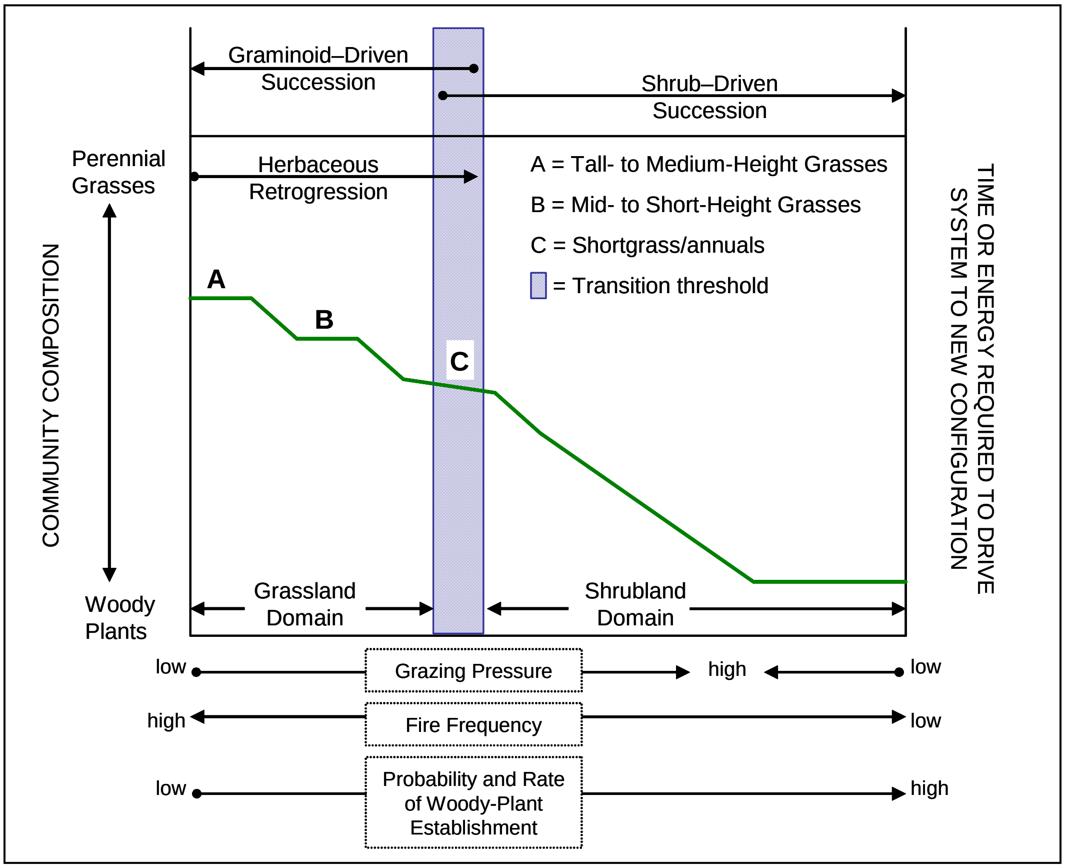

Figure 2. Conceptual Model depicting community structure transition between herbaceous vs. woody plant domination in (Archer 1989).

dominated condition will take vigilant anthropogenic maintenance to prevent the rapid return of a piñon-juniper forest ecosystem (Archer 1989). Costly restoration efforts are required (Whisenant 1999). The energy needed to maintain the stability of the restored grassland is also considerable.

The ball-and-cup diagram provides a helpful illustration of the concept of ecosystem stability (Figure 3). In this diagram the cup represents the natural range of variability in the ecosystem and the ball represents the ecosystem state. The probability of a driver or stressor (Figure 1) forcing the ecosystem across a threshold into a new state depends on its characteristics and magnitude. Ecosystem resilience to the drivers and stressors can of course change as the environmental changes occur. For example, fluctuating climatic conditions may alter the stability of an ecosystem and increase the probability that a separate stressor, such as an insect infestation, could drive the threshold across a threshold.

Grasses can tolerate some grazing (stressor in Figure 1 or 3 (B)). However, if grazing pressure passes a certain threshold, the plant community composition is likely to shift in favor of herbaceous plants. If grazing is eliminated, soil, seed bank, and seedling establishment could potentially drive the community towards the preceding species composition.

Climatic change, atmospheric deposition, overgrazing, and fire suppression, and the complex interactions between these, are potential causes for piñon-juniper encroachment into grassland communities. Spatial and temporal scales will influence the impact of these mechanisms (Archer 1989). Broadly, the vegetation in semi-arid systems such as PECO and CAVO are generally controlled by climate (Chew 1982; Archer 1989). However, climate cannot account for some of the small-scale patterns.

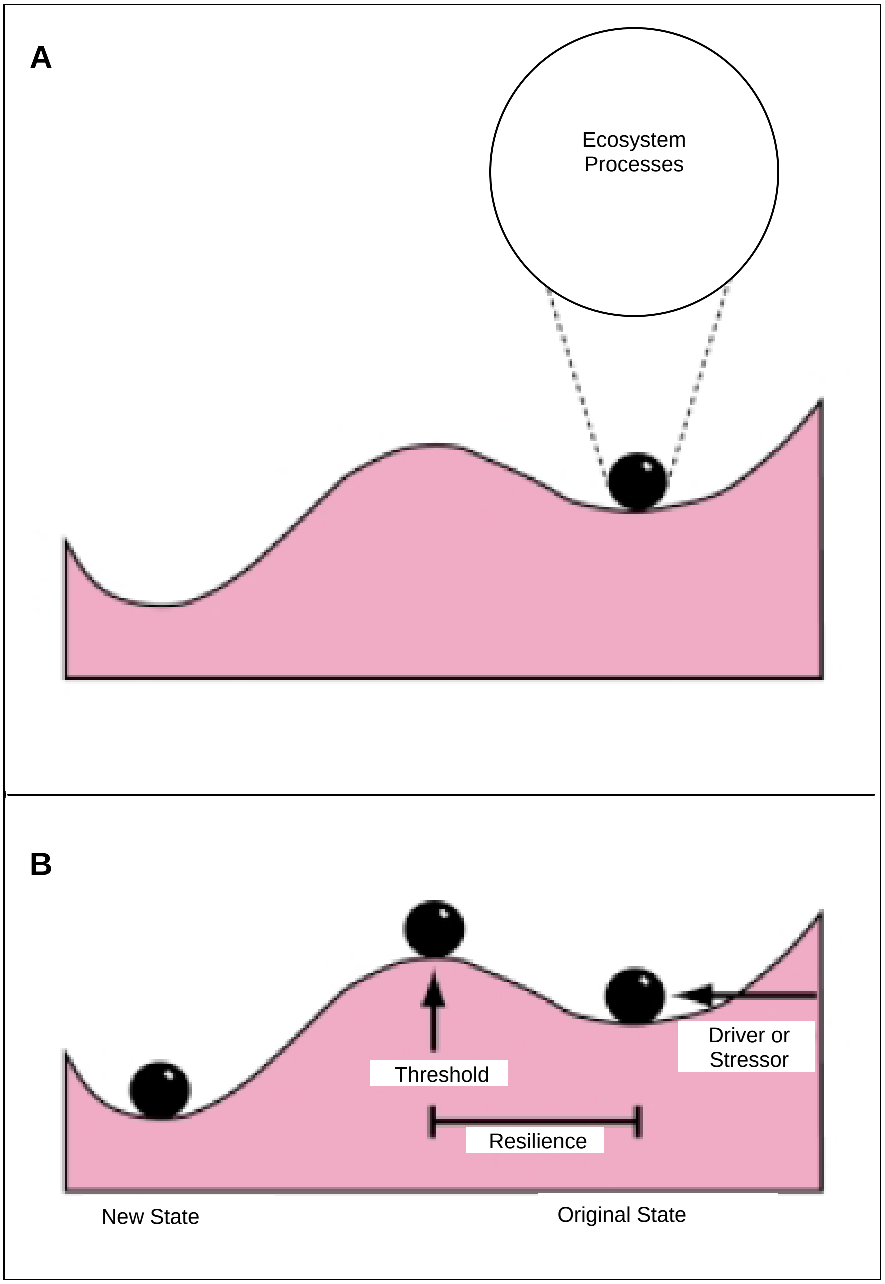

Figure 3. Ball-and-cup diagram integrated with general ecosystem model. In (A), the ecosystem is persisting in its *original state*. In (B), an ecosystem *driver or stressor* is placing pressure on the ecosystem, shifting it to a *new (altered) state*. The magnitude of the *driver or stressor* can face some level of *resilience* by the ecosystem before crossing the *threshold*. After crossing the *threshold*, the energy needed to return the ball, or *ecosystem* to its original state would be considerable. (Derived from Scheffer et al. 2001).

More than just soil moisture will control the expansion of piñon-juniper forests. For example, as the relative values of landform features and mircotopographic features in resource capture increase, piñon-juniper establishment becomes more likely, and the reversion to a Graminoid-dominated system will again require more energy.

PIÑON-JUNIPER FORESTS IN SOPN

Piñon-juniper forests are present in two SOPN Parks, Pecos National Historical Park (PECO) where they are the dominant ecosystem-type, and Capulin Volcano National Monument (CAVO) where they reach the eastern-most edge of their distribution. Within the range of piñon-juniper forests 32 piñon (Pinaceae) and 23 juniper (Cupressaceae) species can be found. However, only one piñon species, *Pinus edulis* (Colorado piñon pine), and two juniper species, *Juniperus monosperma* (one-seeded juniper) and *Juniperus scopulorum* (Rocky Mountain juniper), occur at PECO and CAVO.

Pecos National Historical Park (PECO)
Piñon-juniper forests are the most common vegetation community present at PECO and the surrounding area. Approximately 41% of the Park is covered by piñon-juniper forests, interspersed with ponderosa pine (*Pinus ponderosa*) and Douglas fir (*Pseudotsuga menziesii*). Another 26% of the Park is covered primarily by piñon-juniper communities and 10% with a piñon-juniper/grassland cover. Small areas of old-growth piñon, which is an increasingly rare habitat type in New Mexico, are present (NPS 1984).

PECO lies in the Pecos River valley, in the Rocky Mountain conifer vegetation zone, which is a transition zone between piñon-juniper and ponderosa pine. On the land surrounding PECO, piñon-juniper forests cover the valley floor between the Glorieta Mesa and the foothills of the Sangre de Cristo Mountains. Moreover, most of the land surrounding PECO that has not been developed or grazed is covered by piñon-juniper forests. Interspersed in the piñon-juniper forests, usually on the north-facing slopes of more mesic sites, are clusters of ponderosa pine. On the east side of the Pecos River are larger stands of ponderosa pine and Douglas fir interspersed among the piñon-juniper forests. Additionally, the backcountry zone of PECO is dominated by ponderosa pine and Douglas-fir and has been relatively undisturbed by humans. Cottonwoods (*Populus deltoides*) and willows (*Salix spp.*) dominate the riparian plant community along the Pecos River and Glorieta Creek. Cottonwood trees are dying in areas away from the main channel that were no longer flooded and speculated that these cottonwoods eventually may be replaced by piñon-juniper (Muldavin 1991).

Naturally occurring fires have been suppressed for at least 50 years in the Pecos and Glorieta units. The entire area has been subjected to a long period of human use, including hunting, gathering, cattle and sheep grazing, and grain and fruit production. Lack of fire, human use of the land, and climatic changes are likely the cause for the spread of piñon-junipers into grasslands at lower elevation of PECO and into ponderosa pine forests at higher elevations.

Capulin Volcano National Monument (CAVO)

The piñon-juniper forest community covers approximately 523 acres of CAVO, which is over 60% of the total Monument. The land cover of piñon-juniper forests includes the entire cinder cone and much of the lava boca. Sufficient time has passed since volcanic activity ceased for weathering to decompose much of the lava at CAVO (Harfert no. date). Soil now covers the volcano and the surrounding lands. Capulin Volcano is primarily covered with piñon-juniper forests. These communities began increasing in density and distribution in the late 1800's due to climatic change, grazing pressure, and fire suppression.

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